Renewable Energy and Nuclear

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Roadmap

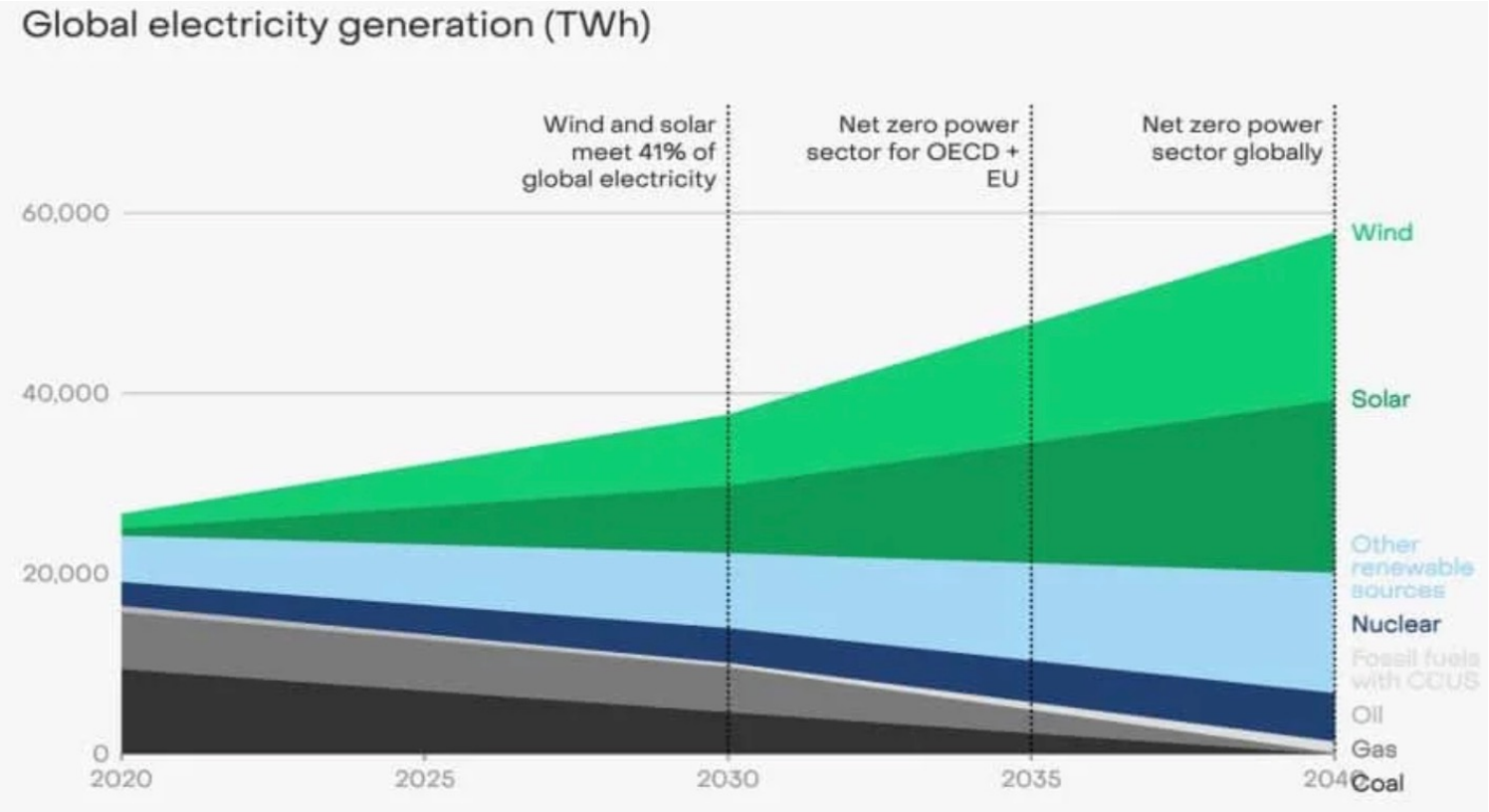
The flexibility challenge

The nuclear power option

Merit order vs. Reliability effect

The increased flexibility challenge

Renewables' pivotal role in decarbonization

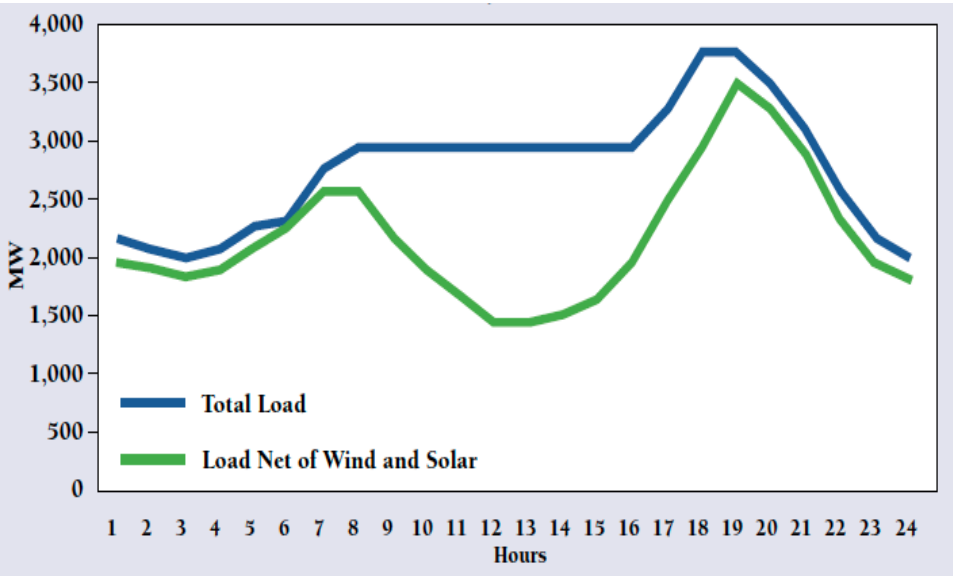


Source: Ember 2023

The duck curve

Total load: *projected* load/demand, by hour, during the day => a moderate diurnal shape

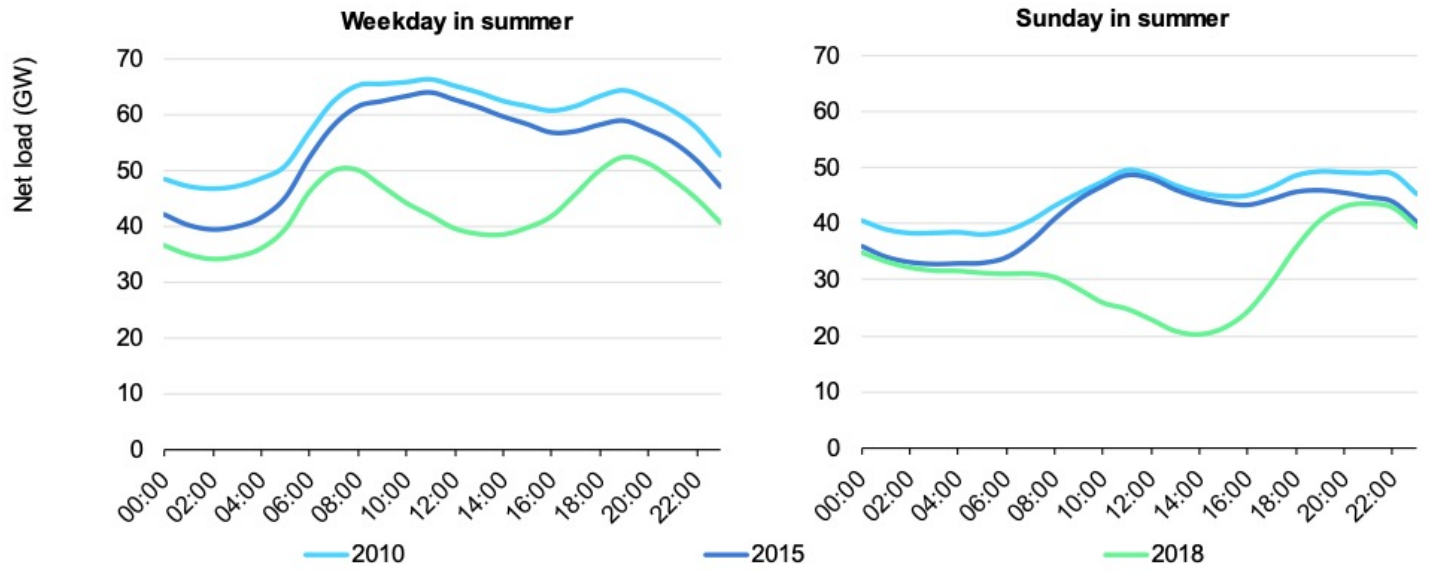
Load net of wind and solar: *expected* load after wind and solar generation have served a portion of the total load.



The issue

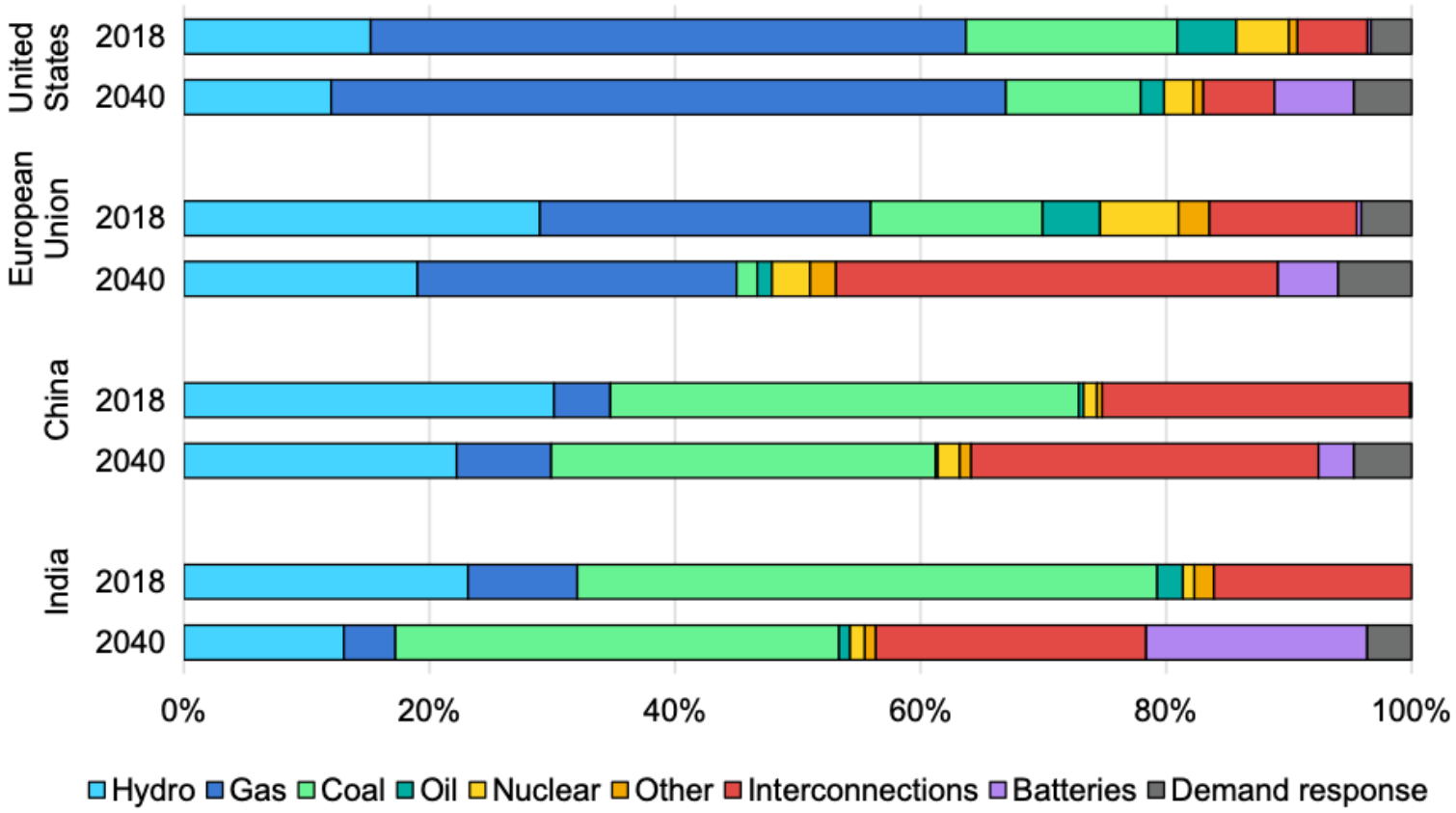
=> the ramping down of conventional supply in the morning (as solar generation increases) and rapid ramping up in the afternoon hours (as loads increase but solar energy supplies drop off quickly) is even more sharp

The increased flexibility challenge in Germany



Source: Based on data from ENTSO-E (2020).

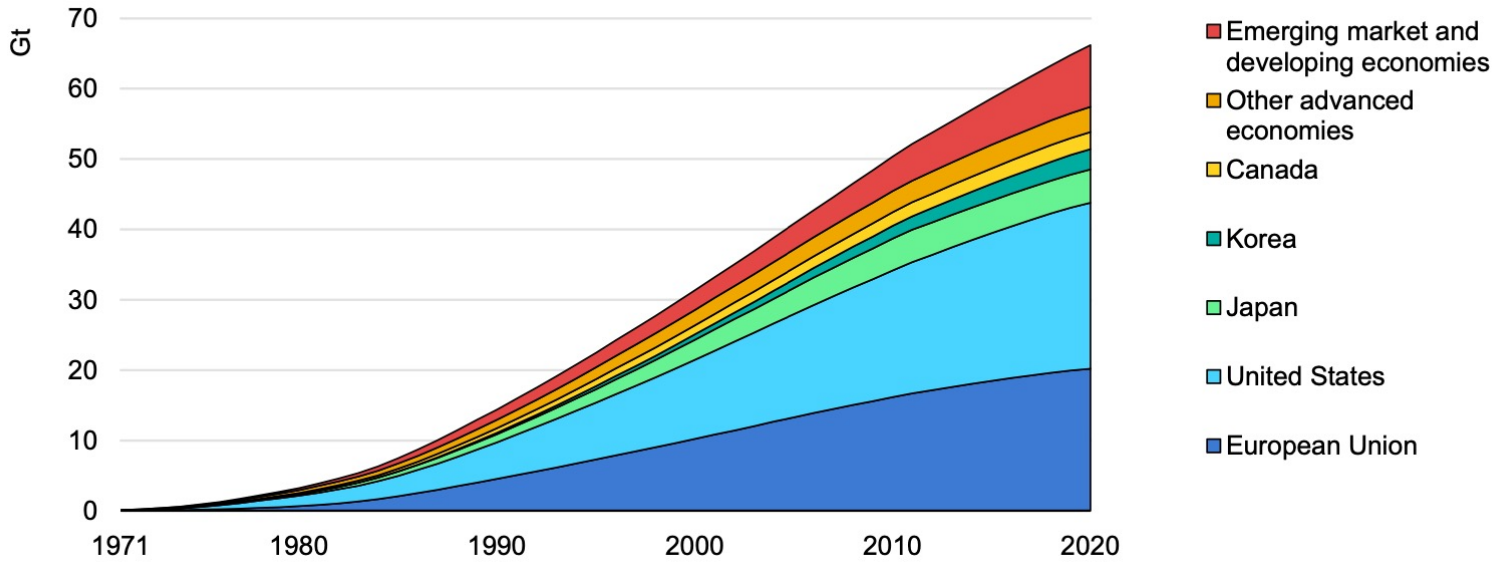
Relative capacity of non-VRE flexibility resources (IEA, 2024)



The nuclear option

Nuclear in the energy transition

Cumulative distribution of CO2 avoided by nuclear power by country/region (IAE, 2023)



IEA's Net Zero by 2050 scenario: nuclear's share of global electricity generation remains similar to today (10%).

Renewable Energy and Nuclear Power: Friends or Foes?

C. Le Coq and S. Schwenen (2024)

- Do intermittent renewables impact the operation of nuclear plants?
- Empirical challenge: isolate the ”renewables” effect
- Approach:
  - Mechanism: renewables lead to more dispatch requests from system operators;
  - Rich dataset: combining nuclear power plants’ outages summary and renewables output in US

Related literature

-the role of new technologies, such as renewable energy and hydrogen, in the power market dynamics

e.g., Acemoglu, Kakhbod, and Ozdaglar (2017); Bushnell and Novan, 2018; Liski and Vehviläinen, (2020), Fabra, N., and Imelda (2023)

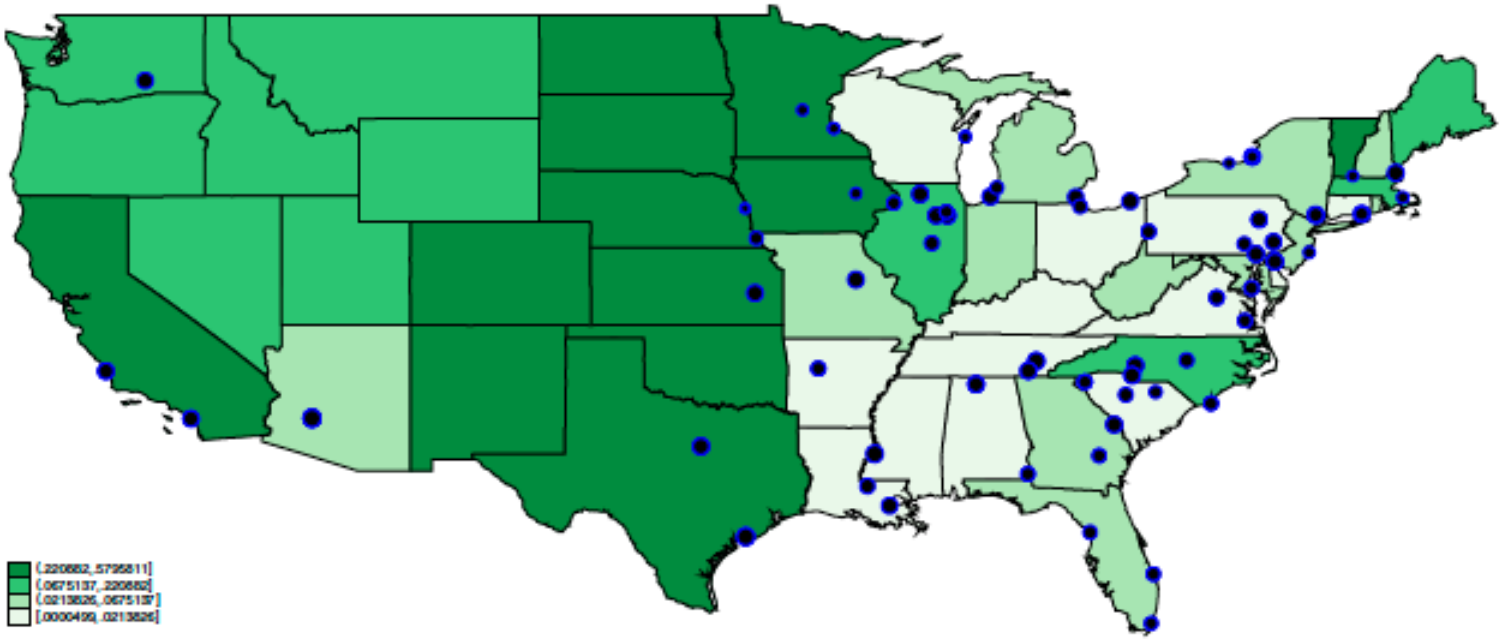
-the nuclear economic performance:

e.g. Wolfram and Davis (2012), Lévêque (2013), Hausmann (2014), Bizet, Bonev, Lévêque (2022)

-the nuclear engineering literature: load-following may trigger Xenon poisoning and delay the ramping up of a nuclear plant (Pouret et al. 2012)

Empirical setup

All commercially US operating nuclear plants and share of renewables



Institution and data

- Nuclear Regulatory Commission (NRC) regulates nuclear safety at the federal level

- **Rich monthly reactors data from US markets (2001-2020)**

- output (MWh),

- (nb. of) outages per month
  - in every case where output is NOT equal to available capacity

- outage motives, e.g., maintenance, failure, load-following, and dispatcher request,
  - we screen the textual descriptions of outages and events in NRC reports and classify the outages according to the motives

Outage due to load following failure -Susquehanna (reactor 1), 2006

(nb. of) outages per month + outage motive

Salem 2	100				
Seabrook 1	98		INCREASING POWER	*	
Susquehanna 1	99		REDUCED POWER FOR LOAD FOLLOWING	*	
Susquehanna 2	100				
Three Mile Island 1	100				
Vermont Yankee	66		DOWNPOWER MANUEVER TO 60% TO PERFORM SINGLE ROD SCRAMS AND PLANNED 345 KV LINE OUTAGE ON LINE #381	*	

Region 2

Unit	Power	Down	Reason or Comment	Change in report (*)	Number of Scrams (#)
Browns Ferry 1	0	03/03/1985	DEFUELED		
Browns Ferry 2	100		2 (500 KV) OF 7 OFFSITE LINES OOS.		
Browns Ferry 3	100		2 (500 KV) OF 7 OFFSITE LINES OOS.		

Outage due to failure- Limerick (reactor 1), 2014

(nb. of) outages per month + outage motive

Region 1

Unit	Power	Down	Reason or Comment	Change in report (*)	Number of Scrams (#)
Beaver Valley 1	100				
Beaver Valley 2	100				
Calvert Cliffs 1	0	02/16/2014	REFUELING OUTAGE		
Calvert Cliffs 2	100				
FitzPatrick	100				
Ginna	100				
Hope Creek 1	100				
Indian Point 2	0	02/23/2014	REFUELING OUTAGE LINE 95891 OOS FOR SCHEDULED MAINTENANCE		
Indian Point 3	100		LINES 96952 AND 95951 ARE RESTRICTED DUE TO UNIT 2 OUTAGE BECAUSE LINE 95891 OOS FOR SCHEDULED MAINTENANCE.	*	
Limerick 1	0	03/04/2014	FORCED OUTAGE - UNIT 1 MANUALLY SCRAMMED DUE TO EHC SYSTEM FAILURE - SEE EN #49871.		

Summary statistics 2001-2020

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Reactor age	24,312	30.53	8.68	0	51
Reactor type (PWR=1)	24,444	0.66	0.47	0	1
All outages	24,418	6.09	10.18	0	31
Maintenance outages	24,418	0.39	2.03	0	31
Load following outages	24,418	0.017	0.30	0	19
Failure outages	24,418	0.01	0.24	0	18
Divested (Yes=1)	24,444	0.43	0.49	0	1
Personnel	22,104	1232.72	663.04	12	3978
Emergency preparedness	22,545	96.92	1.85	88.69	100

Substitution effect of renewables on nuclear

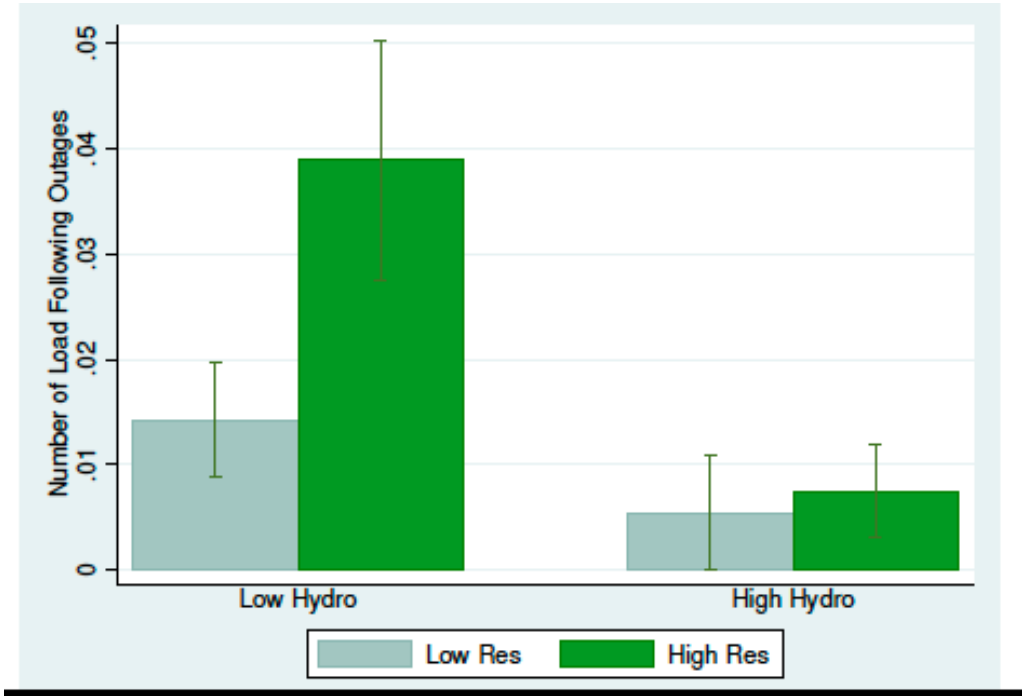
Monthly outage

	(1) All outages	(2) Maintenance	(3) Load following	(4) Failure	(5) Load following	(6) Failure
Renewable output	−0.117	−0.130	0.918***	0.607***	1.200**	0.808***
	(0.086)	(0.093)	(0.340)	(0.161)	(0.540)	(0.309)
Age	0.051	0.117**	−0.376	−0.058	−0.539	−0.150
	(0.053)	(0.055)	(0.424)	(0.079)	(0.348)	(0.103)
Age^2	−0.001	−0.001*	0.004***	0.000	0.006**	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.002)
Monthly trend	−0.002**	−0.008***	0.009	−0.002	0.019	−0.000
	(0.001)	(0.003)	(0.040)	(0.001)	(0.043)	(0.002)
Load					0.000	−0.000
					(0.000)	(0.000)
Personnel					−0.001***	0.000
					(0.000)	(0.000)
Staff preparedness					−0.134	0.073
					(0.168)	(0.090)
Reactor fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,312	24,312	24,312	24,312	20,268	20,268

Standard errors clustered at the operator level in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Substitution effect between nuclear and renewables

Median split for hydro and renewable output



Reliability effect of renewables on nuclear

Monthly outage

	(1) All outages	(2) Maintenance	(3) Load following	(4) **Failure**	(5) Load following	(6) **Failure**
Renewable output	−0.117	−0.130	0.918***	0.607***	1.200**	0.808***
	(0.086)	(0.093)	(0.340)	(0.161)	(0.540)	(0.309)
Age	0.051	0.117**	−0.376	−0.058	−0.539	−0.150
	(0.053)	(0.055)	(0.424)	(0.079)	(0.348)	(0.103)
Age^2	−0.001	−0.001*	0.004***	0.000	0.006**	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.002)
Monthly trend	−0.002**	−0.008***	0.009	−0.002	0.019	−0.000
	(0.001)	(0.003)	(0.040)	(0.001)	(0.043)	(0.002)
Load					0.000	−0.000
					(0.000)	(0.000)
Personnel					−0.001***	0.000
					(0.000)	(0.000)
Staff preparedness					−0.134	0.073
					(0.168)	(0.090)
Reactor fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,312	24,312	24,312	24,312	20,268	20,268

Standard errors clustered at the operator level in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Ownership and Market incentives

Monthly outage

	(1) Load following outages	(2) Failure outages
Renewable output	0.890***	0.606***
	(0.308)	(0.155)
Divested	−2.581***	−1.679*
	(0.988)	(1.020)
Age	−0.377	−0.093
	(0.423)	(0.077)
Age^2	0.005***	0.001
	(0.001)	(0.001)
Monthly time trend	0.009	0.001
	(0.040)	(0.002)
Reactor fixed effects	Yes	Yes
Observations	24,312	24,312

Standard errors clustered at the operator level in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Summary of the results

1. substitution effect: renewables output impacts nuclear outages due to load following request
2. reliability effect: renewables output increases outages due to failure
3. technology portfolio matters: having pump hydro limits both effects
4. ownership matters: deregulated nuclear power plants are less affected (adjust better?) by the renewables effect

Thank you

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http://chloelecoq.org